A proposed master V horizon for the designation of near-surface horizons with vesicular porosity

Judith K. Turk[1], Carrie-Ann Houdeshell[2], and Robert C. Graham[1]
[1]*University of California, Riverside,* [2]*USDA-NRCS, Victorville*

Importance of the vesicular horizon

Surface and near surface horizons with vesicular porosity are a common feature of arid and semi-arid lands and have been referred to as vesicular horizons. Vesicular horizons have been observed in extremely arid, arid, and semi-arid environments around the world (Figure 1) and have even been observed in salt-flats in a sub-humid environment (Figure 1, Ref. 3). Vesicular horizons are characterized by the dominance of vesicular pores, and they typically have platy and/or prismatic or columnar structure, texture classes that are enriched in silt- to fine sand-size particles, and a lighter color than the underlying soil horizons (Figures 2 and 3). Eolian deposition at the soil surface, or beneath a desert pavement, is usually the initial process of vesicular horizon formation. The formation of a desert pavement or a physical or biological crust at the soils surface helps to form the vesicular horizons by creating a surface seal that prevents trapped air from escaping (Evenari et al, 1974) (Fig 4.2a,b). Lastly, cyclic-wetting and drying drives vesicular pore formation by entrapment of air during wetting and expansion of the air as the soil dries, leaving imprints as discontinuous, spherical vesicular pores (Springer, 1958; Miller 1971; Evenari et al., 1974; Figueira and Stoops, 1983) (Figure 4.3b). Also during drying, the vesicular horizon is subject to polygonal cracking, which forms prismatic or columnar structure (Figure 4.3c). As the size of the vesicles increases, the pores become unstable and are subject to collapse, which forms platy structure (Miller, 1971; Figueira and Stoops, 1983) (Figure 4.3d). Vesicular pore formation can be rapid (<1 yr); however, the accumulation of eolian or other silt-rich materials, creating conditions for vesicular pore formation, is the rate-limiting process in vesicular horizon development (Yonovitz and Drohan, 2009). Chronosequence

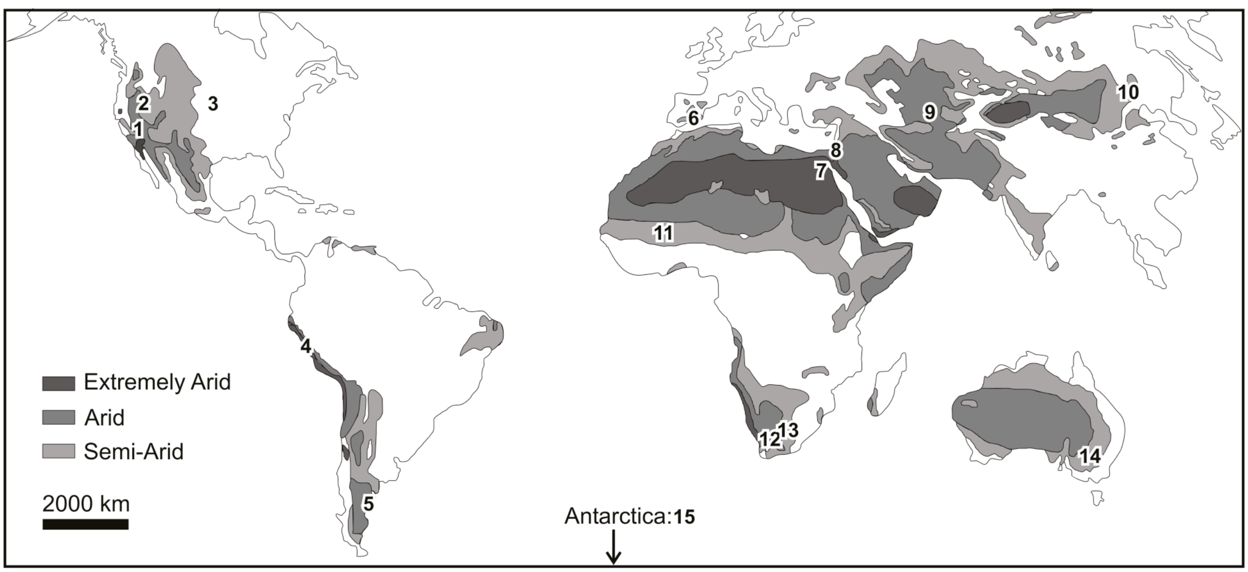

Figure 1. Examples of studies recognizing vesicular horizons around the world, in relation to the global distribution of extremely arid, arid, and semi-arid lands (USGS, 1997, Turk and Graham, *in review*). References: (1) McDonald, 1994, (2) Blackburn, 1975, (3) Joeckel and Clement, 1999, (4) Noller, 1993, (5) Bouza et al., 1994, (6) Cantón et al., 2003; (7) Adelsberer and Smith, 2009; (8) Amit and Gerson, 1986; (9) Paletskaya et al., 1958; (10) Lebedeva et al., 2009; (11) Valentin, 1994; (12) Ellis, 1990; (13) Henning and Kellner, 1994; (14) Brown and Dunkerley, 1996; (15) Bockheim, 2010.

studies in the Mojave Desert reveal that vesicular horizons increased in thickness and vesicular porosity throughout the Holocene and are generally best expressed on non-eroded Pleistocene landforms (Reheis et al., 1989, McDonald et al., 1995). These landforms have a long history of dust

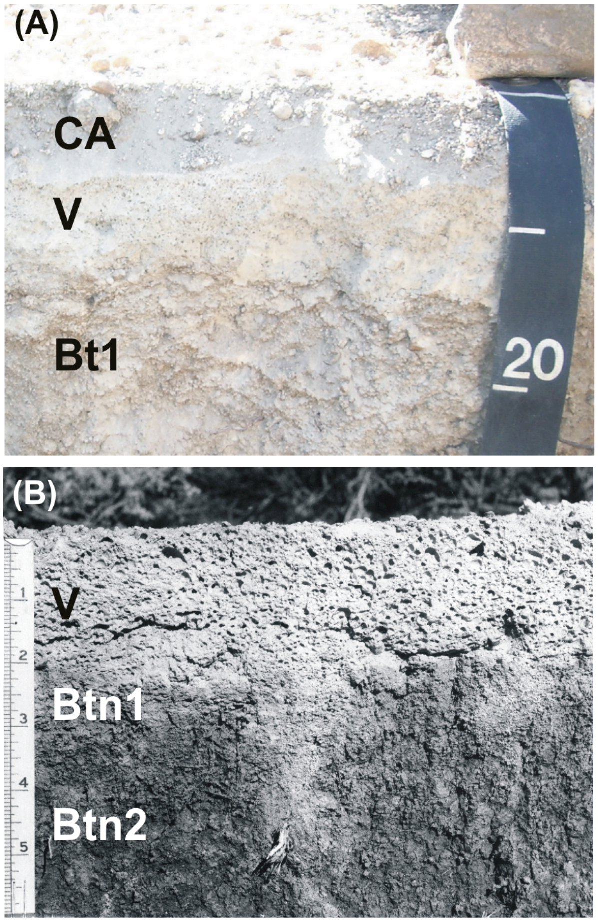

Figure 2. Soil profiles with vesicular horizons (V): (A) V horizon under a grus layer in Owen's Valley, CA (Photo by A.M. Rossi, scale in cm) and (B) V horizon in the Gardenerville soil series (Photo by W.N. Johnson, scale in inches).

deposition and experienced a large influx of eolian materials due to the drying of pluvial lakes during the Pleistocene to Holocene transition (McFadden et al., 1998). Platy structure is observed in vesicular horizons as young as 750 yrs (McDonald, 1994), while prismatic structure is observed in vesicular horizons that are >10,000 yrs old (Meadows et al., 2008).

Vesicular horizons are of interest to ecologists and hydrologists because they regulate the distribution of water, a critical function in the water-limited arid lands where they occur. Vesicular horizons greatly reduce infiltration rates (Table 1, Figure 5) and increase water retention near the soil surface (Young et al., 2004), thus increasing water loss to runoff and evaporation. The amount of vesicular porosity in surface soils has a significant negative correlation with infiltration rates (Blackburn, 1975; Valentin, 1994; Lebedeva et al., 2009). This is because the vesicular pores are not inter-connected and therefore do not promote water movement through the horizon. The low infiltration rate of the vesicular horizon decreases water available to leach subsoil salinity (Young et al., 2004; Wood et

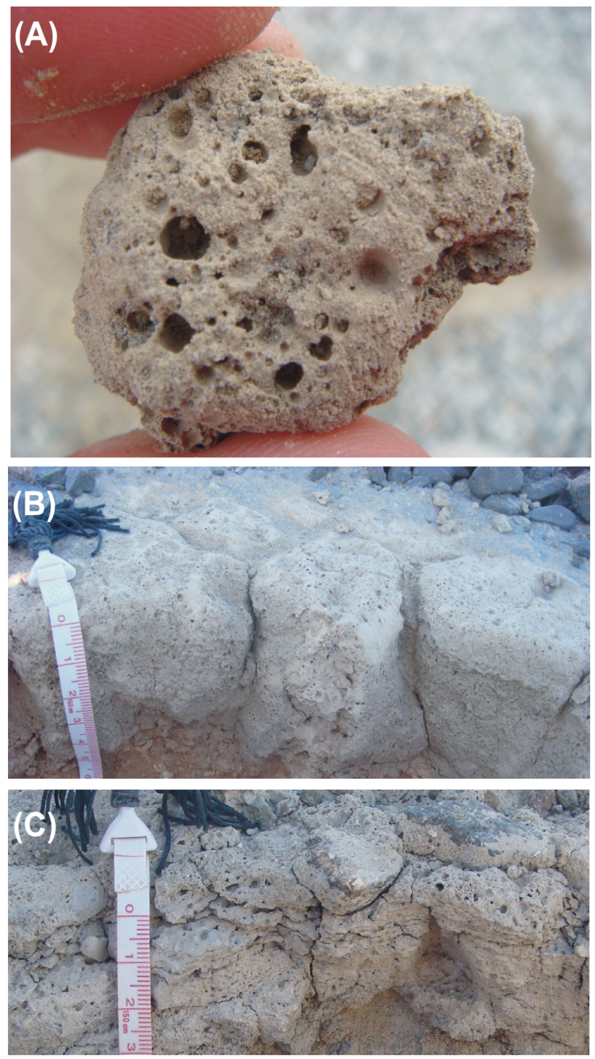

Figure 3. Photos illustrating morphological features of vesicular horizons: (A) vesicular porosity, (B) columnar structure (desert pavement removed on surface), and (C) platy structure (Photos by J.K. Turk, scales in cm).

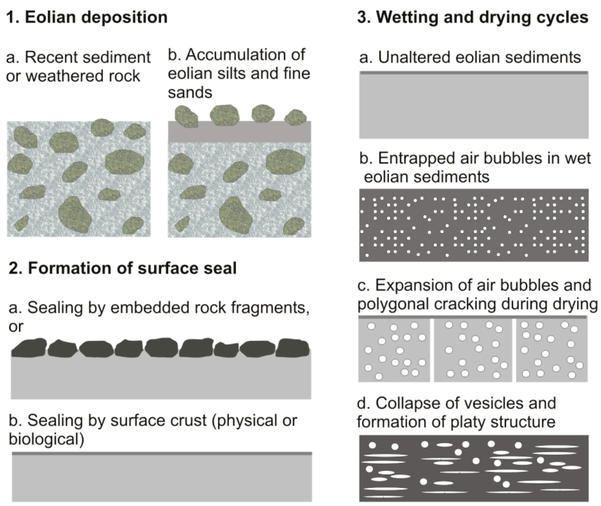

Fig. 4. Summary of processes central to vesicular horizon formation (Turk and Graham, *in review*).

al., 2005) and can lead to subsoil accumulation of very soluble salts (nitrates and chlorides) (Graham et al., 2008). The land area with vesicular horizons has expanded in conjunction with degradation of semi-arid rangelands in such areas as Nevada (Eckert et al., 1986) and South Africa (Henning and Kellner, 1994). Geomorphologists study vesicular horizons, and associated desert pavements, in order to interpret the stability of geomorphic surfaces (Amit and Gerson, 1986; Bockheim, 2010). Vesicular horizon thickness and vesicular porosity correlate well with soil age (Turk and Graham, *in review*).

Vesicular horizons are also a concern for land managers because they are formed in eolian material (McFadden et al., 1987), making them a hazard for dust mobilization when disturbed (Goossens and Buck, 2009). Such disturbance of vesicular horizons can be expected to increase with the development of vast areas of desert lands for solar and wind power facilities. Current proposals for solar power development include 7,300 km^2 of desert lands in the western United States (Associated Press, 2010). The impact of disturbed vesicular horizons will extend far beyond the deserts. Dust released by human disturbance of soils has been linked to important ecological and hydrological effects. Snowpacks coated with dust have decreased albedo, which increases snow melt. This phenomenon impacts the amount and timing of runoff, which are critical to ecosystems in the arid southwestern United States (Painter et al., 2010).

Vesicular horizons have a unique genetic

Table 1. Comparison of infiltration rates of soils with vesicular (V) horizons (in shrub interspace and desert pavement) and soils with A horizons (in shrub islands, washes, and young alluvium) in various desert regions.

Region	Dominant Vegetation	V horizon Cover*	Infiltration Rate ($cm\ hr^{-1}$) V	A	Reference
Sonoran Desert	*Larrea divaricata*, *Ambrosia dumosa*	DP	0.8	6.0-9.6	Musick, 1975
Central Mojave	*Larrea tridentata*, *Ambrosia dumosa*, *Yucca* spp.	DP	0.3-0.8	6.8-15	Young et al., 2004
Central Mojave	*Larrea tridentata*	DP	1.3-4.6	8.9	Miller et al., 2009
Northern Mojave	*Coleogyne ramossima*, *Ephedra nevadensis*, *Atriplex canescens*	DP	1.2-4.5	5.5-17	Shafer et al., 2007
Northern Mojave	*Larrea tridentata*, *Coleogyne ramosissimum*	DP	0.4-1.4	3.1-3.2	Eckert et al., 1979
Great Basin	*Artemisia* spp.	BG	1.7-3.2	5.8-7.2	Blackburn, 1975
Patagonia	*Chuquiraga avellanedae*	DP	0.6	4.1	Rostagno, 1989

*DP = Desert Pavement, BG=Bare Ground

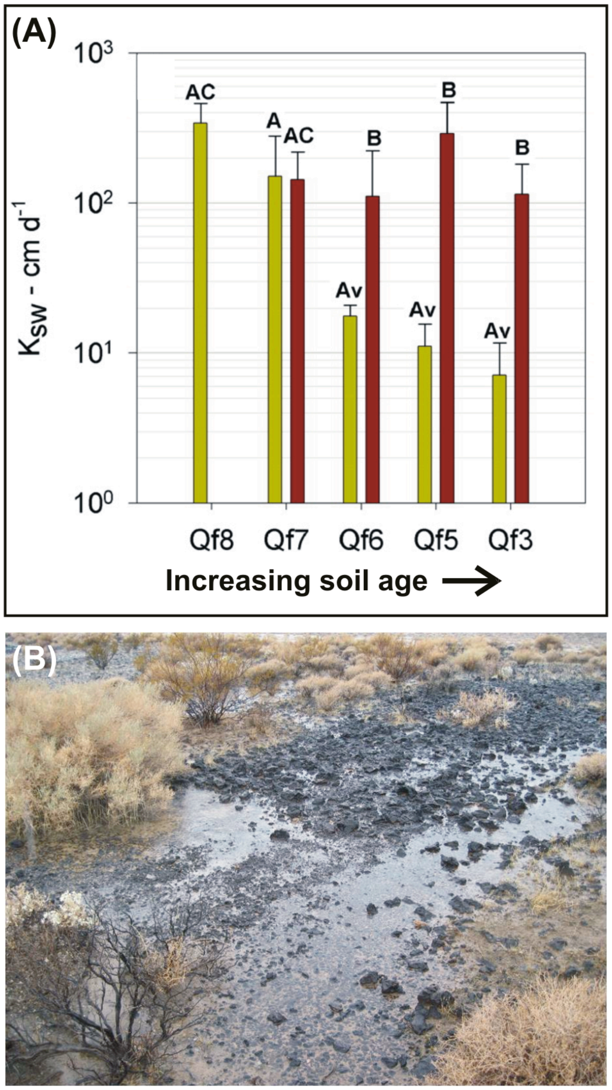

Figure 5. The influence of vesicular horizons on infiltration rates shown by: (A) the increase in infiltration rate (K_{sw}) when the vesicular horizon is removed (red bars labled "B") compared to surfaces with intact vesicular horizons (yellow bars labeled "Av") (Young et al., 2004) and (B) the ponding of water on a desert pavement surface with an underlying vesicular horizon during a rainstorm in the Mojave Desert (Photo by R.C. Graham).

origin and a distinctive and dynamic morphology. They are sensitive to land management and impact the air quality and soil hydrology of desert, semi-desert, and dry steppe ecosystems.

In the western United States there are 1092 soil series with a vesicular horizon in the Official Series Description (OSD), which represent a total mapped area of about 156,000 km^2 (39 million acres) (Figure 6) (Turk and Graham, *in review*). In this assessment, vesicular horizons were recognized as soil horizons starting within 10 cm of the soil surface, in which vesicular pores are more common than any other pore type. These soils occur mostly within Land Resource Region D, which includes the Basin and Range Province and the adjacent Intermontane Plateaus (e.g., Colorado and Columbia Plateau provinces) (Figure 6). These soils include Aridisols (n = 686), Mollisols (n = 173), Entisols (n = 134), Alfisols (n = 58), Inceptisols (n = 31), Andisols (n = 5), and Vertisols (n=5).

There is a clear need for terminology to designate the vesicular horizon. In 1958, the "Av" horizon designation was introduced to the scientific literature to indicate surface horizons with vesicular porosity (Springer, 1958); a convention that has persisted outside of the National Cooperative Soil Survey (NCSS) and is widely used in studies of desert geomorphology, soils, and ecosystems (Table 2). In the World Reference Base soil classification system, the vesicular layer is part of the yermic diagnostic horizon and is defined by its "polygonal network of desiccation cracks, often filled with in-blown material, that extend into the underlying layers" and "weak to moderate platy structure" (IUSS Working Group WRB, 2006). The NCSS system for designating genetic soil horizons currently does not recognize the vesicular horizon (Soil Survey Staff, 2006).

Current status of vesicular horizon designation

In NCSS mapping, most vesicular horizons are currently designated as A horizons and occasionally (3% of OSDs) as E horizons (see attached Examples 1-5 from the OSD database). However, they do not fit the main concept of the A horizon; that is,

"Mineral horizons that have formed at the surface or below an O horizon. They exhibit obliteration of all or much of the original rock structure and show one or both of the following: (1) an accumulation of humified organic matter closely mixed with the mineral fraction and not dominated by properties characteristic of E or B horizons or (2) properties resulting from cultivation, pasturing,

or similar kinds of disturbance" (Soil Survey Staff, 2010).

Vesicular horizons generally do not contain an accumulation of humified organic matter or occur below an O horizon. The median organic carbon (OC) content of vesicular horizons in the NRCS database is 0.7% (Turk and Graham, *in review*), which is within the range of OC contents measured in dust from the Chihuahuan Desert (0.28 to 1.1%) (Li et al., 2009). Most OC in the vesicular horizon is likely inherited from dust, rather than accumulated *in situ*. Vesicular horizons are typically best expressed in the interspace between shrubs, where there is minimal biomass to add organic matter to the soil surface.

The text that accompanies the A horizon definition in Chapter 18 of Keys to Soil Taxonomy provides an exception that allows vesicular horizons to be designated A horizons even though they are quite different from the main concept: "In some areas, such as areas of warm, arid climates, the undisturbed surface horizon is less dark than the adjacent underlying horizon and contains only small amounts of organic matter. It has a morphology distinct from the C layer, although the mineral fraction is unaltered or only slightly altered by weathering. Such a horizon is designated as an A horizon because it is at the surface."

The current designation of vesicular horizons as A horizons is unsatisfactory because it does not highlight the presence of this critical pedogenic layer or distinguish it from horizons that meet the main concept of the A horizon. Because vesicular horizons are lumped with A horizons, the soil description does not emphasize the uniqueness of this horizon to the reader. These two types of surface horizons could hardly be more different: the "main concept" A horizon is enriched in and darkened by humified organic carbon and generally supports rapid infiltration of water,

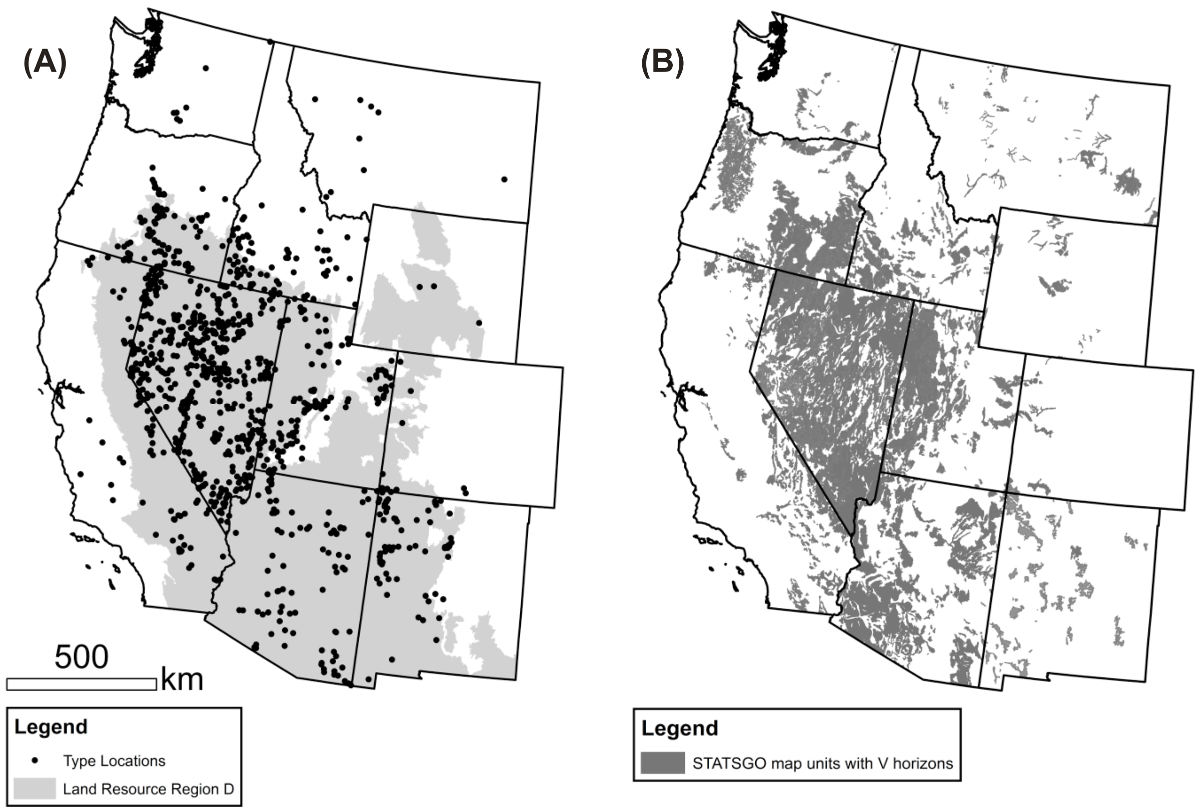

Figure 6. Maps showing vesicular horizon distribution: (A) type locations of soil series with vesicular horizons in the Official Series Description and (B) State Soil Geographic database (STATSGO) map units with one or more soil series with vesicular horizons as a major component (Turk and Graham, *in review*).

whereas the vesicular horizon is typically light colored, has a low organic carbon content, and severely restricts infiltration. It has even been suggested that the presence of organic matter may inhibit the formation of vesicular pores. In a study of seed germination in Great Basin soils, vesicular porosity was observed to be better expressed in the interspace soils (1.3 % organic matter) compared to the coppice dune ("shrub island") soils (5.1% organic matter) (Wood et al., 1978). The authors found that removal of organic matter from the coppice dune soils promoted formation of vesicular pores under saturation-drying cycles.

Vesicular horizons may, in some cases, have properties of other master horizons (E, B, or C), but they are not adequately described by any one of these horizons in all cases.

E horizon consideration: E horizons are defined as:

"Mineral horizons in which the main feature is the loss of silicate clay, iron, aluminum, or some combination of these, leaving a concentration of sand and silt particles. These horizons exhibit obliteration of all or much of the original rock structure" (Soil Survey Staff, 2010).

Vesicular horizons may overlie Bt horizons,

Table 2. Examples of studies using the designation "Av" to indicate a surface horizon with vesicular porosity.

Reference	Region	Type of Study
Springer et al., 1958	Carson Desert, NV	Soil science
Peterson, 1980	Mojave Desert, CA	Geomorphology
Figueira and Stoops, 1983	North Patagonia, Argentina	Soil science
Amit and Gerson, 1986	Negev Desert, Israel	Geomorphology
Eckert et al., 1986	Great Basin, NV	Range management
McFadden et al., 1986	Mojave Desert, CA	Soil science
McFadden et al., 1987	Mojave Desert, CA	Geomorphology
McFadden, 1988	Mojave Desert, CA	Geomorphology
Reheis et al., 1989	Mojave Desert, CA	Soil science
McFadden et al., 1992	Mojave Desert, CA	Soil science
Reheis et al., 1992	Mojave Desert, CA	Soil science
Amit et al., 1993	Negev Desert, Israel	Soil science
Bouza et al., 1993	Central Patagonia, Argentina	Soil science
Noller, 1993	Peruvian Desert, Peru	Geomorphology
McDonald et al., 1995	Mojave Desert, CA	Geomorphology
Wells et al., 1995	Mojave Desert, CA	Geomorphology
Blank et al., 1996	Great Basin, NV	Soil science
McFadden et al., 1998	Mojave Desert, CA	Geomorphology
Quade, 2001	Mojave Desert, CA and NV	Geomorphology
Anderson et al., 2002	Mojave Desert, CA	Soil science
Young et al., 2004	Mojave Desert, CA	Hydrology
Wood et al., 2005	Mojave Desert, CA	Soil science
McAuliffe and McDonald, 2006	Sonoran Desert, AZ	Geomorphology
Valentine and Harrington, 2006	Mojave Desert, NV	Geomorphology
Pelletier et al., 2007	Mojave Desert, CA and NV	Geomorphology
Shafer et al., 2007	Mojave Desert, NV	Ecology
Meadows et al., 2008	Mojave Desert, CA	Geomorphology
Adelsberger and Smith, 2009	Sahara Desert, Egypt	Geomorphology
Goossens and Buck, 2009	Mojave Desert, NV	Geomorphology
Miller et al., 2009	Mojave Desert, CA	Ecology
Reheis et al., 2009	Mojave Desert and southern Great Basin, CA and NV	Geomorphology

suggesting that they function as a source of illuvial clays (Reheis et al., 1992; Appendix, see Examples 1, 2, 3, and 5), but they are not the same as an E horizon. Evidence of eluviation that distinguishes E horizons, include "a color of higher value or lower chroma, or both" and/or "a coarser texture" compared to the underlying B horizon (Soil Survey Staff, 2010). These morphological properties may be observed in vesicular horizons, but are the result of eolian additions rather than (or in addition to) elluviation. Eolian materials that accumulate in the vesicular horizon are silt-rich and often contain light-colored minerals (e.g., calcite and gypsum) and have low Fe-oxide content (Reheis et al., 1995), leading to a morphology similar to that of the eluviated E horizons. The vesicular horizons fall into the category of soil material that is specifically excluded from the definition of albic materials: "Relatively unaltered layers of light colored sand, volcanic ash, or other materials deposited by wind or water are not considered albic materials, although they may have the same color and apparent morphology" (Soil Survey Staff, 2010). Although this criteria applies only to the diagnostic albic horizon, not to the morphological E horizon, the definition of the E horizon does refer to the "loss" of silicate clay, iron, and aluminum, therefore it is important to consider whether the morphology of the horizon is actually indicative of removal of these materials or due to inherited properties of the parent material.

To illustrate the difference in processes involved in formation of E horizons versus vesicular horizons, it is useful to consider that 68% of vesicular horizons contain measureable $CaCO_3$ (Turk and Graham, *in review*). Although $CaCO_3$ content is not considered in the definition of the E horizon, it is commonly accepted that leaching of $CaCO_3$, which promotes the flocculation of clays when it is present, is a prerequisite to significant transport of clays (Muhs, 1984; Vidic and Lobnik, 1997). Thus, the common occurrence of $CaCO_3$ in vesicular horizons suggests that eluviation is not a dominant process, therefore distinguishing vesicular horizons from E horizons.

B horizon consideration: B horizons are defined as:

"Horizons that have formed below an A, E, or O horizon. They are dominated by the obliteration of all or much of the original rock structure and show one or more of the following:

1. Illuvial concentrations of silicate clay, iron, aluminum, humus, carbonate, gypsum, or silica, alone or in combination;
2. Evidence of the removal or addition of carbonates;
3. Residual concentration of oxides;
4. Coatings of sesquioxides that make the horizon conspicuously lower in color value, higher in chroma, or redder in hue, without apparent illuvation of iron;
5. Alteration that forms silicate clay or liberates oxides, or both, and that forms a granular, blocky, or prismatic structure if volume changes accompany changes in moisture content;
6. Brittleness; *or*
7. Strong gleying" (Soil Survey Staff, 2010).

Most vesicular horizons are immediately excluded from the definition of the B horizon because they occur at the soil surface (Appendix, see Examples 1, 2, 3, and 5). However, in some cases there is evidence for the translocation of silicate clays within the vesicular horizons. Clay content may increase from the exterior to the interior of columnar peds that part to platy structure and argillans may form along the surfaces of platy peds (Anderson et al., 2002). In such cases, the vesicular horizon includes both zones of clay loss (E horizons) and zones of "illuvial concentration of silicate clay" (B horizons) (Soil Survey Staff, 2010).

Vesicular horizons have also been designated as "Bv" horizons when they occur immediately beneath the desert pavement, because of the author's interpretations that the vesicular horizon is formed in translocated weathering products of the desert pavement clasts (Bockheim, 2010). Although evidence for accumulation of translocated materials may be found in some vesicular horizons, this process does not adequately define all vesicular horizons.

C horizon consideration: C horizons are defined as:

"Horizons or layers, excluding strongly cemented and harder bedrock, that are little affected by pedogenic processes and lack the properties of O, A, E, or B horizons. Most are mineral layers. The

material of C layers may be either like or unlike the material from which the solum has presumably formed. The C horizon may have been modified, even if there is no evidence of pedogenesis."

In some cases, vesicular pores are observed to form in very young soil material (<100 yrs) with little other evidence for pedogenic development and in the presence of fine stratification (Gile and Hawley, 1968). If the specific pedogenic processes that distinguish the vesicular horizon (Figure 4) are not recognized, these horizons should be considered C horizons.

The need for a new horizon

We contend that the distinct genetic origin and the important hydrological behavior of horizons with predominantly vesicular pores warrant a unique master horizon designation. We recognize that some of these horizons have properties in common with other master horizons. In those cases, designation of transitional or combination horizons, such as VA or BVt, would be appropriate.

Because there is no USDA-NRCS recognition and designation for vesicular horizons, these horizons are not obvious when looking at Official Series Descriptions or NASIS pedon descriptions. A user of soil survey information must thoroughly read a soil horizon description to find the important pedogenic features (e.g., vesicular pores, platy structure, etc.). A horizon designation is needed that immediately alerts users to the vesicular horizon. Increased awareness of the vesicular horizon as a distinct morphologic horizon, will enhance the recognition of its hydrological, ecological, pedogenic, and land management importance.

Proposed horizon designation

We propose the addition of a new genetic horizon to NCSS terminology (Chapter 3 of Soil Survey Manual, Chapter 18 of Keys to Soil Taxonomy) that specifically indicates the presence of a vesicular horizon. The choice of nomenclature for the proposed horizon requires careful consideration of how the vesicular horizon fits into the existing range of master horizons and suffix designations. The commonly used "Av horizon" is not a possibility because it conflicts with the usage of the subscript "v" to indicate plinthite. While some modification of this suffix symbol (e.g., ve or vv) would provide a quick fix, it would not address the disparity between the current master horizon definitions and the properties of the vast majority of vesicular horizons. We believe that given the distinct genetic origin of the vesicular horizon, the most appropriate designation is a master V horizon. The most influential pedogenic processes in the vesicular horizon are the accumulation of dust-derived materials (e.g., silt, carbonate), sealing of the soil surface, and cyclic wetting and drying that leads to the formation of vesicular pores, platy structure, and polygonal cracking (see Figure 4).

The master V horizon will highlight one of the most important features of arid and semi-arid soils. The designation will draw attention to the distinctive properties that are critical to hydrology, ecosystem function, and environmental quality. The master V designation will also improve the quality of data collected in ongoing soil survey projects because soil mappers will have an avenue to express this key soil physical property that will bring it to the forefront of the description. As a result, soil surveys will clearly identify where vesicular horizons occur, thereby providing spatial information that is essential for management of arid and semi-arid lands (e.g., relative to infiltration rate, susceptibility to wind erosion, dust generating potential).

Definition and usage of master V horizon

V horizons: Mineral horizons that have formed at the soil surface, or below a layer of rock fragments (e.g., desert pavement) or a physical or biological crust. They are characterized by the predominance of vesicular pores.

Porosity in a V horizon may include vughs and collapsed vesicles, in addition to the spherical vesicular pores. Other types of pores (e.g., interstitial, tubular) must occur in a lower quantity than the vesicular pores. V horizons are usually formed in eolian material, although the underlying soil horizons may be formed in residuum, alluvium, or other transported materials. V horizons are typically enriched in silt through fine sand particle-size fractions. Common structures in the V horizon include platy, prismatic, and columnar aggregates. The underlying B horizons are not dominated by vesicular porosity.

Inclusion of this definition in Chapter 18 of Keys to Soil Taxonomy will require the following modifications to other horizon definitions (modifications are underlined):

A horizons: *Mineral horizons that have formed at the surface or below an O horizon. They exhibit obliteration of all or much of the original rock structure and show one or both of the following: (1) an accumulation of humified organic matter closely mixed with the mineral fraction and not dominated by properties characteristic of V, E, or B horizons or (2) properties resulting from cultivation, pasturing, or similar kinds of disturbance.*

B horizons: *Horizons that may have formed below an A, V, E, or O horizon. They are dominated by the obliteration of all or much of the original rock structure by the obliteration of all or much of the original rock structure …*

C horizons: Horizons or layers, excluding strongly cemented and harder bedrock, that are little affected by pedogenic processes and lack the properties of O, A, V, E, or B horizons. Most are mineral layers. The material of C layers may be either like or unlike the material from which the solum has presumably formed. The C horizon may have been modified, even if there is no evidence of pedogenisis.

Transitional horizons using the master V horizon are logical under certain circumstances. AV or VA horizons may occur where the horizon is both enriched in organic matter and contains vesicular pores (e.g., mollic epipedons with vesicular porosity). BV or VB horizons may describe vesicular horizons containing clay or carbonate coatings, or other properties of the underlying B horizon.

Transitional horizons grading between V and E horizons (i.e., EV or VE horizons) generally are not meaningful horizon designations because the morphological features that are indicative of eluviation (e.g., lighter color and coarser texture than the underlying horizon) are too similar to be distinguished from typical morphologic features of the V horizon resulting from eolian additions. Some V horizons may be influenced by eluvial processes, however, the eolian influence on the vesicular horizon commonly obscures evidence of eluviation. Thus, the V horizon designation typically overrides the E horizon designation. An analogous situation is the designation "A" for an eluvial horizon enriched in organic matter. Even though silicate clays have been lost (eluviated) from the horizon, we do not call it an E horizon because the organic matter accumulation takes precedence.

Combination horizons of the V horizon with other master horizons may occur in bioturbated zones, such as shrub islands or in areas where surface cover associated with the vesicular horizon (e.g., desert pavement) is patchy.

Judging from the subscripts currently used for horizons with vesicular porosity (Soil Survey Staff, 2009), the V horizon is most likely to be used with: t, k, y, n, z, p, and b. Although there is little or no overlying soil from which to leach materials such as clays and carbonates, these materials are sometimes deposited with eolian dust and translocated to form coatings within the vesicular horizons (Sullivan and Koppi, 1991; Anderson et al., 2002). The p suffix symbol may be used to indicate disturbance to the vesicular horizon. Vesicular pores generally reform quickly after physical disruption, as demonstrated by observations of similar vesicular pore morphology in disturbed and undisturbed soils during the first year after disturbance (Yonovitz and Drohan, 2009).

Often, the vesicular horizon is formed predominantly in eolian material and the underlying horizons may be formed in other parent material (e.g., alluvium). However, because there is some mixing of the parent materials (Reheis et al., 2009), vesicular horizons that are influenced by eolian additions should not be indicated by lithologic discontinuities. Instead, they are the result of cumulization processes.

References

Adelsberger, K.A., and J.R. Smith. 2009. Desert pavement development and landscape stability on the Eastern Libyan Plateau, Egypt. Geomorphology 107:178-194.

Amit, R., and R. Gerson. 1986. The evolution of Holocene reg (gravelly) soils in deserts - an example from the Dead Sea region. Catena 13:59-79.

Amit, R., R. Gerson, and D.H. Yaalon. 1993. Stages and rate of the gravel shattering process by salts in desert reg soils. Geoderma 57:295-324.

Anderson, K., S. Wells, and R. Graham. 2002. Pedogenesis of vesicular horizons, Cima Volcanic Field, Mojave Desert, California. Soil Sci. Soc. Am. J. 66:878-887.

Associated Press. 2010. Solar showdown in tortoises' home [Online]. Available by MSNBC at <http://www.msnbc.msn.com/id/34659369/ns/us_news-environment/> (verified 11 Nov. 2010).

Blackburn, W.H. 1975. Factors influencing infiltration and sediment production of semiarid rangelands in Nevada. Water Resour. Res. 11:929-937.

Blank, R.R., J.A. Young, and T. Lugaski. 1996. Pedogenesis on talus slopes, the Buckskin range, Nevada, USA. Geoderma 71:121-142.

Bockheim, J.G. 2010. Evolution of desert pavements and the vesicular layer in soils of the Transantarctic Mountains. Geomorphology 118:433-443.

Bouza, P., H.F. Delvalle, and P.A. Imbellone. 1993. Micromorphological, Physical, and Chemical Characteristics of Soil Crust Types of the Central Patagonia Region, Argentina. Arid Soil Research and Rehabilitation 7:355-368.

Brown, K.J., and D.L. Dunkerley. 1996. The influence of hillslope gradient, regolith texture, stone size and stone position on the presence of a vesicular layer and related aspects of hillslope hydrologic processes: A case study from the Australian arid zone. Catena 26:71-84.

Cantón, Y., A. Solé-Benet, and R. Lázaro. 2003. Soil-geomorphology relations in gypsiferous materials of the Tabernas Desert (Almeria, SE spain). Geoderma 115:193-222.

Eckert, R.E., M.K. Wood, W.H. Blackburn, and F.F. Peterson. 1979. Impacts of off-road vehicles on infiltration and sediment production of two desert soils. J. Range Manage. 32:394-397.

Eckert, R.E., F.F. Peterson, and J.T. Belton. 1986. Relation between ecological-range condition and proportion of soil-surface types. J. Range Manage. 39:409-414.

Ellis, F. 1990. Note on soils with vesicular structure and other micromorphological features in Karoo soils., pp. 326-336. 16th Congress of the Soil Science Society of South Africa, Pretoria.

Evenari, M., D.H. Yaalon, and Y. Gutterman. 1974. Note on soils with vesicular structure in deserts. Z. Geomorphol. 18:162-172.

Figueira, H., and G. Stoops. 1983. Application of micromorphometric techniques to the experimental study of vesicular layer formation. Pedologie 33:77-89.

Gile, L.H., and J.W. Hawley. 1968. Age and comparative development of desert soils at Gardner Spring radiocarbon site, New Mexico. Soil Sci. Soc. Am. Proc. 32:709-716.

Goossens, D., and B. Buck. 2009. Dust emission by off-road driving: Experiments on 17 arid soil types, Nevada, USA. Geomorphology 107:118-138.

Graham, R.C., D.R. Hirmas, Y.A. Wood, and C. Amrhein. 2008. Large near-surface nitrate pools in soils capped by desert pavement in the Mojave Desert, California. Geology 36:259-262.

Henning, J.A.G., and K. Kellner. 1994. Degradation of a soil (Aridosol) and vegetation in the semiarid grasslands of southern Africa. Bot. Bull. Acad. Sin. 35:195-199.

Joeckel, R.M., and B.A. Clement. 1999. Surface features of the Salt Basin of Lancaster County, Nebraska. Catena 34:243-275.

Lebedeva, M.P., D.L. Golovanov, and S.A. Inozemtsev. 2009. Microfabrics of desert soils of Mongolia. Euras. Soil Sci. 42:1204-1217.

Li, J.R., G.S. Okin, and H.E. Epstein. 2009. Effects of enhanced wind erosion on surface soil texture and characteristics of windblown sediments. J. Geophys. Res.-Biogeosciences 114:G02003, doi:10.1029/2008JG000903.

McDonald, E.V. 1994. The relative influences of climatic change, desert dust, and lithologic control on soil-geomorphic processes and soil hydrology of calcic soils formed on quaternary alluvial-fan deposits in the Mojave Desert, California. Ph.D. Dissertation, The University of New Mexico, Albuquerque, NM.

McDonald, E.V., L.D. McFadden, and S.G. Wells. 1995. The relative influences of climate change, desert dust, and lithologic control on soil-geomorphic processes on alluvial fans, Mojave

Desert, California: Summary of results, p. 35-42, *In* R. E. Reynolds and J. Reynolds, eds. Ancient surfaces of the East Mojave Desert : a volume and field trip guide prepared in conjunction with the 1995 Desert Research Symposium. San Bernardino County Museum Association, Redlands, CA.

McFadden, L.D. 1988. Climatic influences on rates and processes of soil development in Quaternary deposits of southern California. Geol. Soc. Am. Spec. Pap. 216:153-177.

McFadden, L.D., E.V. McDonald, S.G. Wells, K. Anderson, J. Quade, and S.L. Forman. 1998. The vesicular layer and carbonate collars of desert soils and pavements: formation, age and relation to climate change. Geomorphology 24:101-145.

McFadden, L.D., S.G. Wells, W.J. Brown, and Y. Enzel. 1992. Soil genesis on beach ridges of pluvial Lake Mojave: Implications for Holocene lacustrine and eolian events in the Mojave Desert, southern California. Catena 19:77-97.

McFadden, L.D., S.G. Wells, and J.C. Dohrenwend. 1986. Influences of Quaternary climatic changes on processes of soil development on desert loess deposits of the Cima Volcanic Field, California. Catena 13:361-389.

McFadden, L.D., S.G. Wells, and M.J. Jercinovich. 1987. Influences of eolian and pedogenic processes on the origin and evolution of desert pavements. Geology 15:504-508.

Meadows, D.G., M.H. Young, and E.V. McDonald. 2008. Influence of relative surface age on hydraulic properties and infiltration on soils associated with desert pavements. Catena 72:169-178.

Miller, D.E. 1971. Formation of Vesicular Structure in Soil. Soil Sci. Soc. Am. Proc. 35:635-637.

Miller, D.M., D.R. Bedford, D.L. Hughson, E.V. McDonald, S.E. Robinson, and K.M. Schmidt. 2009. Mapping Mojave Desert ecosystem properties with surficial geology., p. 225-251, *In* R. H. Webb, et al., eds. The Mojave Desert: Ecosystem Processes and Sustainability. University of Nevada Press, Reno, NV.

Muhs, D.R. 1984. Intrinsic thresholds in soil systems. Phys. Geogr. 5: 99-770.

Musick. 1975. Barrenness of desert pavement in Yuma County, Arizona. Journal of the Arizona Academy of Science 10:24-28.

Noller, J.S. 1993. Late Cenozoic stratigraphy and soil geomorphology of the Peruvian Desert, 3^{o}-18^{o}S: A long-term record of hyperaridity and El Niño. Ph.D. Dissertation, University of Colorado, Boulder.

Painter, T.H., J.S. Deems, J. Belnap, A.F. Hamlet, C.C. Landry, and B. Udall. 2010. Response of Colorado River runoff to dust radiative forcing in snow. Proc. Natl. Acad. Sci. USA 107:17125-17130.

Paletskaya, L.N., A.P. Lavrov, and S.I. Kogan. 1958. Pore formation in takyr crust. Sov. Soil Sci. (Engl. Transl.) 3:245-250.

Pelletier, J.D., M. Cline, and S.B. DeLong. 2007. Desert pavement dynamics: numerical modeling and field-based calibration. Earth Surf Process Landforms 32:1913-1927.

Peterson, F.F. 1980. Holocene desert soil formation under sodium-salt influence in a playa-margin environment. Quaternary Research 13:172-186.

Quade, J. 2001. Desert pavements and associated rock varnish in the Mojave Desert: How old can they be? Geology 29:855-858.

McAuliffe, J.R., and E.V. McDonald. 2006. Holocene environmental change and vegeation contraction in the Sonoran Desert. Quaternary Research 65:204-215.

Reheis, M.C., J.W. Harden, L.D. Mcfadden, and R.R. Shroba. 1989. Development rates of late quaternarysoils, Silver Lake Playa, California. Soil Sci. Soc. Am. J. 53:1127-1140.

Reheis, M.C., J.M. Sowers, E.M. Taylor, L.D. Mcfadden, and J.W. Harden. 1992. Morphology and genesis of carbonate soils on the Kyle Canyon fan, Nevada, USA. Geoderma 52:303-342.

Reheis, M.C., J.C. Goodmacher, J.W. Harden, L.D. Mcfadden, T.K. Rockwell, R.R. Shroba, J.M. Sowers, and E.M. Taylor. 1995. Quaternary Soils and Dust Deposition in Southern Nevada and California. Geological Society of America Bulletin 107:1003-1022.

Reheis, M.C., J.R. Budahn, P.J. Lamothe, and R.L. Reynolds. 2009. Compositions of modern dust and surface sediments in the Desert Southwest, United States. J. Geophys. Res. - Earth Surface 114:F01028, doi:10.1029/2008JF001009.

Rostagno, C.M. 1989. Infiltration and sediment production as affected by soil surface conditions in a shrubland of Patagonia, Argentina. J. Range Manage. 42:382-385.
Shafer, D.S., M.H. Young, S.F. Zitzer, T.G. Caldwell, and E.V. McDonald. 2007. Impacts of interrelated biotic and abiotic processes during the past 125 000 years of landscape evolution in the Northern Mojave Desert, Nevada, USA. J. Arid Environ. 69:633-657.
Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture, 2009. Official Soil Series Descriptions [Online]. Available by USDA-NRCS http://soils.usda.gov/technical/classification/osd/index.html (verified 24 June 2009).
Soil Survey Staff. 2010. Keys to Soil Taxonomy, 11th ed. USDA Natural Resources Conservation Service, Washington, DC.
Springer, M.E. 1958. Desert pavement and vesicular layer of some soils of the desert of the Lahontan Basin, Nevada. Soil Sci. Soc. Am. Proc. 22:63-66.
Sullivan, L.A., and A.J. Koppi. 1991. Morphology and genesis of silt and clay coatings in the vesicular layer of a desert loam soil. Aust. J. Soil Res. 29:579-586.
Turk, J.K. and R.C. Graham. *In review*. Distribution and properties of vesicular horizons in the western United States. Soil Sci. Soc. Am. J.
United States Geological Survey, 1997. Distribution of Non-Polar Arid Lands [Online]. Available by USGS <http://pubs.usgs.gov/gip/deserts/what/world.html> (verified 25 Jan. 2011).
Valentin, C. 1994. Surface sealing as affected by various rock fragment covers in West-Africa. Catena 23:87-97.
Valentine, G.A., and C.D. Harrington. 2006. Clast size controls and longevity of Pleistocene desert pavements at Lathrop Wells and Red Cone volcanoes, southern Nevada. Geology 34:533-536.
Vidic, N.J., and F. Lobnik. 1997. Rates of soil development of the chronosequence in the Ljubljana Basin, Slovenia. Geoderma 76:35-64.
Wells, S.G., L.D. Mcfadden, J. Poths, and C.T. Olinger. 1995. Cosmogenic 3He surface-exposure dating of stone pavements: Implications for landscape evolution in deserts. Geology 23:613-616.
Wood, M.K., W.H. Blackburn, R.E. Eckert, and F.F. Peterson. 1978. Interrelations of physical-properties of coppice dune and vesicular dune interspace soils with grass seedling emergence. J. Range Manage. 31:189-192.
Wood, Y.A., R.C. Graham, and S.G. Wells. 2005. Surface control of desert pavement pedologic process and landscape function, Cima Volcanic field, Mojave Desert, California. Catena 59:205-230.
Yonovitz, M., and P.J. Drohan. 2009. Pore morphology characteristics of vesicular horizons in undisturbed and disturbed arid soils; implications for arid land management. Soil Use Manage. 25:293-302.
Young, M.H., E.V. McDonald, T.G. Caldwell, S.G. Benner, and D.G. Meadows. 2004. Hydraulic properties of a desert soil chronosequence in the Mojave Desert, USA. Vadose Zone J. 3:956-963.

APPENDIX: Examples of proposed master V horizon usage

Example #1: ACTEM

Family: Clayey, smectitic, frigid, shallow Xeric Argidurids

Location: Harney County, Oregon

Explanation: This description illustrates the typical usage of the proposed master V horizon, where the horizon occurs at the surface, is light in color, and has platy structure.

A (Proposed V)--0 to 5 cm; light gray (10YR 7/2) cobbly loam, brown (10YR 4/3) moist; weak medium platy structure; hard, very friable, slightly sticky and slightly plastic; common fine and common medium roots; many fine and medium vesicular pores; 10 percent gravel and 10 percent cobbles; neutral (pH 7.3); clear wavy boundary. (5 to 18 cm thick)

Bt--5 to 18 cm; brown (10YR 5/3) clay, yellowish brown (10YR 5/4) moist; moderate and strong coarse subangular blocky structure; hard, firm, very sticky and very plastic; common fine and common medium roots; many fine and medium irregular pores; common distinct clay films on faces of peds; slightly alkaline (pH 7.4); clear wavy boundary.

Btk--18 to 38 cm; light yellowish brown (10YR 6/4) clay loam, dark yellowish brown (10YR 4/4) moist; moderate medium subangular blocky structure parting to moderate fine angular blocky; hard, firm, moderately sticky and moderately plastic; common fine and common medium roots; many fine irregular pores; common distinct clay films on faces of peds; secondary carbonates are finely disseminated in the matrix; strongly effervescent; slightly alkaline (pH 7.5); clear wavy boundary. (Combined thickness of the Bt and Btk horizons is 13 to 40 cm)

Bkqm--38 to 51 cm; very pale brown (10YR 8/3) cemented material, pale brown (10YR 6/3) moist; moderate very thick platy structure; very rigid; indurated by secondary silica; few fine roots between plates; secondary carbonates are finely disseminated in the matrix; strongly effervescent; abrupt smooth boundary. (10 to 25 cm thick)

2R--51 inches; basalt.

Example #2: OLDALE (tentative series)

Family: Loamy-skeletal, mixed, superactive, hyperthermic Typic Haplargids

Location: Riverside County, CA: Joshua Tree National Park Soil Survey Area

Explanation: This description is an example of a tentative soil series in an active mapping area that could be improved by the use of a master V horizon. Most current initial soil mapping areas are in LRR D, where vesicular horizons are a common feature. Furthermore, this description is an example that includes a V horizon, as well as a transitional BV horizon. The BV horizon is transitional because it has vesicular pores and silt loam texture like the V horizon, but has a redder hue and subangular blocky structure like the Bt1 horizon.

A1 (Proposed V) --0 to 3 centimeters; light yellowish brown (10YR 6/4) very gravelly silt loam, dark yellowish brown (10YR 4/4) moist; weak thin platy structure; loose, nonsticky and nonplastic; common fine and medium vesicular pores; violently effervescent; 40 percent gravel and 7 percent cobbles; moderately alkaline (pH 8.0); clear smooth boundary.

A2 (Proposed BV) --3 to 12 centimeters; brown (7.5YR 5/4) gravelly silt loam, brown (7.5YR 4/4) moist; moderate medium subangular blocky structure; soft, very friable, moderately sticky and moderately plastic; very few fine roots; common fine vesicular pores; violently effervescent; 15 percent gravel and 5 percent cobble; moderately alkaline (pH 8.0); clear wavy boundary.

Bt1 --12 to 34 centimeters; reddish brown (5YR 4/4) extremely gravelly loam, reddish brown (5YR 4/4) moist; moderate medium subangular blocky structure; slightly hard, friable, moderately sticky and moderately plastic; few fine tubular pores; common, distinct, clay films on all faces of peds; noneffervescent; 55 percent gravel and 5 percent cobbles; slightly acid (pH 6.2); clear wavy boundary.

Bt2 --34 to 64 centimeters: reddish brown (5YR 4/4) extremely gravelly sandy loam, reddish brown (5YR 4/4) moist; moderate fine subangular blocky structure; hard, firm, slightly sticky and slightly plastic; few fine tubular pores; few, distinct, clay films on all faces of peds; non effervescent; 50 percent gravel and 10 percent cobbles; moderately acid (pH 5.8); abrupt, wavy boundary. (Combined thickness of the 2Bt horizon is 28 to 51 centimeters)

C --64 to 150 centimeters; brown (7.5YR 5/4) very gravelly loamy sand, brown (7.5YR 4/4) moist; single grain; loose, nonsticky and nonplastic; very few very fine interstitial pores; noneffervescent; 30 percent gravel and 5 percent cobbles; moderately acid (pH 5.8).

Example #3: GARDENERVILLE (Figure 2b)

Family: Fine, smectitic, mesic Durinodic Xeric Natrargids

Location: Douglas County, NV

Explanation: This description demonstrates the substitution of a V horizon for a horizon that has been designated as an E horizon. The predominance of vesicular porosity, together with platy structure, in this horizon suggests that it is best described as a V horizon.

E (Proposed V)--0 to 2 inches; gray (10YR 6/1) fine sandy loam, dark gray (10YR 4/1) moist; weak thick platy structure; slightly hard, friable, slightly sticky and nonplastic; many very fine and many fine roots; many fine and medium vesicular pores; neutral (pH 7.1); abrupt wavy boundary. (1 to 3 inches thick)

Btn1--2 to 2.5 inches; grayish brown (10YR 5/2) clay loam, very dark grayish brown (10YR 3/2) moist; weak medium platy structure; very hard, friable, moderately sticky and moderately plastic; many very fine and many fine roots; few very fine interstitial and many very fine tubular pores; few faint clay films on faces of peds and lining pores; moderately alkaline (pH 7.9); abrupt broken boundary. (0.5 to 3 inches thick)

Btn2--2.5 to 5.5 inches; brown (10YR 5/3) clay, brown (10YR 4/3) moist; moderate medium prismatic structure parting to strong very fine subangular blocky; hard, friable, very sticky and very plastic; common very fine and few fine roots; many very fine interstitial and few very fine tubular pores; common distinct clay films on faces of peds and lining pores; moderately alkaline (pH 8.0); moderately sodic (SAR 14); abrupt smooth boundary. (2 to 6 inches thick)

Btn3--5.5 to 8 inches; brown (10YR 5/3) clay, brown (10YR 4/3) moist; weak medium prismatic structure parting to moderate medium subangular blocky; hard, firm, very sticky and very plastic; common very fine and few fine roots; few very fine tubular, and common very fine and fine interstitial pores; common distinct clay films on faces of peds and lining pores; moderately alkaline (pH 8.1); moderately sodic (SAR 15); clear wavy boundary. (2 to 6 inches thick)

Btnk--8 to 16 inches; grayish brown (10YR 5/2) sandy clay loam, brown (10YR 4/3) moist; massive; hard, friable, moderately sticky and moderately plastic; few very fine and few fine roots; few very fine and few fine interstitial and tubular pores; common faint clay bridges between sand grains and common faint clay films lining pores; secondary carbonates segregated as common fine and very fine very pale brown (10YR 8/2) masses; slightly effervescent in matrix and violently effervescent on carbonates; strongly alkaline (pH 9.0); moderately sodic (SAR 17); clear wavy boundary. (5 to 10 inches thick)

Bqkn--16 to 35 inches; brown (10YR 5/3) coarse sandy loam, brown (10YR 4/3) moist; massive; hard, firm and brittle, slightly sticky and nonplastic; few very fine roots; few fine and very fine interstitial pores; few thin silica bridges between sand grains; about 25 percent weakly cemented durinodes; secondary carbonates segregated as few fine and very fine very pale brown (10YR 8/2) masses; noneffervescent in matrix and slightly effervescent on carbonates; few fine distinct dark brown (7.5YR 3/2) masses of iron accumulation; strongly alkaline (pH 8.7); moderately sodic (SAR 15); clear smooth boundary. (12 to 24 inches thick)

Bq--35 to 58 inches; brown (10YR 5/3) and pale brown (10YR 6/3) loamy coarse sand, dark brown (10YR 3/3) and brown (10YR 4/3) moist; massive; slightly hard, firm and brittle, nonsticky and nonplastic; few very fine roots; few very fine and fine interstitial pores; about 20 percent weakly cemented durinodes; common medium and coarse distinct dark brown (7.5YR 3/2) masses of iron accumulation; slightly alkaline (pH 7.8); clear smooth boundary. (12 to 24 inches thick)

C--58 to 67 inches; yellow (10YR 7/6) coarse sand, yellowish brown (10YR 5/8) moist; single grain; loose, nonsticky and nonplastic; many very fine interstitial pores; common coarse prominent black (10YR 2/1) masses of manganese accumulation and common coarse prominent brown (7.5YR 4/3) masses of iron accumulation; slightly alkaline (pH 7.7).

Example #4: PINTWATER

Family: Loamy-skeletal, mixed, superactive, calcareous, mesic Lithic Torriorthents

Location: Lincoln County, NV

Explanation: This description provides an example in which the vesicular horizon occurs near the surface, rather than at the surface. This horizon still meets the definition of the V horizon, as long as it is the user's interpretation that the V horizon *formed* as the surface and the overlying A horizon formed in material that was added after V horizon formation.

A1 (Proposed A)--0 to 3 cm; light brownish gray (10YR 6/2) gravelly fine sandy loam, dark grayish brown (10YR 4/2) moist; massive; soft, very friable, nonsticky and nonplastic; few very fine and fine roots; many very fine and fine interstitial pores; 20 percent pebbles; strongly effervescent; contains considerable mica, sanidine, and clear quartz crystals; strongly alkaline (pH 8.5); abrupt smooth boundary. (0 to 5 cm thick)

A2 (Proposed V)--3 to 10 cm; pale brown (10YR 6/3) gravelly sandy loam, dark grayish brown (10YR 4/2) moist; weak coarse platy structure; slightly hard, very friable, nonsticky and nonplastic; few fine and very fine roots; many fine and medium vesicular pores; 20 percent pebbles; strongly effervescent; strongly alkaline (pH 8.7); clear smooth boundary. (8 to 18 cm thick)

Bqk--10 to 50 cm; very pale brown (10YR 7/3) very stony fine sandy loam, brown (10YR 5/3) moist; massive; soft, very friable, nonsticky and nonplastic; many fine and very fine roots; many very fine and fine interstitial pores; 15 percent stones, 15 percent cobbles, and 15 percent pebbles; violently effervescent with few to common fine flecks of segregated secondary calcium carbonate and secondary silica with secondary calcium carbonate pendants on bottom of rock fragments; strongly alkaline (pH 8.5); clear wavy boundary. (13 to 43 cm thick)

R--50 cm; very pale brown (10YR 8/2) fractured welded tuff, brown (10YR 5/3) moist; secondary silica calcium carbonate coats in fractures and on the bottom of each loose rock fragment, often as pendants.

Example #5: ADAMATT

Family: Ashy-skeletal, glassy, frigid, shallow Vitrandic Argixerolls

Location: Mono County, CA

Explanation: This description provides an example in which the vesicular horizon has dark colors, indicating the presence of organic matter. Thus, this horizon does have characteristics of an A horizon, but the vesicular porosity and platy structure make it more like a V horizon. We propose the designation of this horizon as a transitional VA horizon.

A (Proposed VA)--0 to 8 cm; grayish brown (10YR 5/2) very gravelly ashy sandy loam, very dark grayish brown (10YR 3/2) moist; moderate medium platy structure parting to moderate fine and medium subangular blocky; slightly hard, very friable, nonsticky and nonplastic; few fine and medium roots; many very fine and fine vesicular and common very fine and fine interstitial pores; 25 percent subangular gravel and 10 percent subangular cobbles; slightly acid (pH 6.1); clear wavy boundary. (5 to 13 cm thick)

Bt1--8 to 28 cm; brown (10YR 5/3) very cobbly ashy sandy loam, dark brown (10YR 3/3) moist; moderate medium subangular blocky structure; slightly hard, friable, slightly sticky and nonplastic; common very fine to coarse roots; common very fine and fine interstitial and common very fine tubular pores; 5 percent faint clay bridges between sand grains; 10 percent subangular paragravel; 30 percent subangular gravel and 15 percent subangular cobbles; slightly acid (pH 6.5); clear wavy boundary. (13 to 25 cm thick)

Bt2--28 to 43 cm; brown (10YR 5/3) very gravelly ashy sandy loam, dark brown (10YR 3/3) moist; moderate medium subangular blocky structure; hard, firm, slightly sticky and nonplastic; common very fine to medium roots; common very fine and fine interstitial and common very fine tubular pores; 50 percent faint clay films lining pores and on faces of peds; 20 percent paragravel; 40 percent subangular gravel and 15 percent subangular cobbles; slightly acid (pH 6.4); clear wavy boundary. (13 to 20 cm thick)

Cr--43 to 56 cm; weathered andesite bedrock.